ENGINEERING TRIPOS PART IIA

Tuesday 6 May 2003 2.30 to 4.00

Module 3D1

SOIL MECHANICS

Answer not more than 3 questions.

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

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1 A mountainous region has a deep and narrow valley originally cut by a glacier and now containing a river whose flow rate varies with the seasons. A glacial till of clayey, sandy silt is found in a shallow layer on the valley floor. It has a specific gravity of solids G_s = 2.65, and a natural water content of about 14%. It is proposed to use it to construct the core of an embankment dam for flood-control. Standard Proctor compaction data of bulk density ρ and water content w for the glacial till are given below.

w %	6	10	14	18
ρ kg m^{-3}	1908	2082	2127	2053

(a) On the graph paper provided, plot voids ratio versus water content at compaction for the glacial till. Show lines of saturation ratio S_r = 1, 0.8, 0.6, and 0.4. Estimate the voids ratio for Proctor optimum compaction. Calculate the corresponding dry density ρ_d and explain why engineers usually prefer this to voids ratio in analysing compaction data. How could compactability in the field be related to the Proctor test in the laboratory?

[40%]

(b) Estimate the optimum water content for laboratory compaction, and explain the increase in voids ratio on either side of that water content.

[20%]

(c) The dam is to be built in the dry season, and it is expected that stockpiles of the glacial till extracted from borrow-pits will desiccate to some extent prior to compaction. The engineer responsible for the dam construction identifies pore water suction as the cause of the enhanced stiffness and strength of the glacial till when it is compacted dry of optimum. He believes that it should swell negligibly due to the loss of suction when the reservoir fills, since the clay content is only about 10%. He therefore proposes to demand a compacted voids ratio no higher than 0.45, but is relaxed about the water content. Comment on your agreement or disagreement with each of these views and proposals, and make your own recommendation.

[40%]

2 A normally consolidated clay lies 6 m deep on top of sand. More free-draining sand is to be used as compacted fill for land reclamation to bring 1 hectare of the ground surface to an elevation 2 m above the water table which will remain at the original elevation of the clay surface. The average density of the sand fill is expected to be 1800 kg m^{-3}. It is required to estimate the volume of sand that will be required, and therefore the reduction in the volume of the clay due to compression.

A 0.6 m long core was recovered from 2.7 to 3.3 m depth in the clay. It possessed an average bulk density of 1600 kg m^{-3}. It was noticed that there was a 50 mm thick zone of sand near the middle of the core. A sample of clay was trimmed for an oedometer test. The clay was brought back into equilibrium under a vertical effective stress of 20 kPa prior to the imposition of a stress increment of magnitude 50 kPa which caused the following compressions of the 20 mm thick disc, which could drain to both the top and the bottom.

time t min	1	4	9	16	25	36	49
compression ρ mm	0.43	0.83	1.25	1.61	1.84	2.02	2.05

(a) Estimate the stiffness E_o and the coefficient of consolidation C_v of the oedometer sample. Deduce a consistent value of the vertical permeability k of the clay.

[40%]

(b) Discuss whether the conduct of the oedometer test fits the required application. If necessary, modify the values derived in (a) for use with a representative element of clay compressing in the field.

[20%]

(c) Make an initial estimate of the ultimate settlement of the 6 m clay layer under 2 m of the imposed fill, and the settlement that might be recorded 12 months after filling, when the construction of facilities is to start. Point out any additional assumptions that you have introduced.

[20%]

(d) Estimate the mass of sand required for the reclamation if the required ground elevation is to be achieved, and point to any improvements which should still be made to the ground investigation or calculation procedure.

[20%]

(TURN OVER

3 (a) The Cam Clay model of soil behaviour reflects at element scale the micro-mechanics of grain contact elasticity, grain crushing, and grain rearrangement. Use a sketch of a yield surface in (τ, σ', v) space to indicate which parameters or attributes of the model reflect these three micro-mechanisms.

[20%]

(b) Using values given in the Soil Mechanics Databook, specify consolidation stress histories by which a reconstituted soil similar to London Clay could be saturated and set up in a Simple Shear Apparatus (SSA) with a voids ratio of 1, either in state A at an over-consolidation ratio (*OCR*) of 1, or in state B at an *OCR* of 10. Explain why both samples should give the same undrained strength, and calculate it. Show effective stress paths in (τ, σ', v) space for each of the SSA simple shear tests from states A and B, and indicate ultimate values of excess pore water pressure.

[50%]

(c) Practising engineers obtain the *apparent cohesion* of clays from routine ground investigations. But they should also know about *stress history* and *drainage*. Adding where necessary to the effective stress paths drawn in (b), explain the practical importance of these three aspects of the nature of clays.

[30%]

4 (a) Why is knowledge of the relative density I_D of sand insufficient to predict its strength and dilatancy?

[25%]

(b) Using values given in the Soil Mechanics Databook, estimate the vertical effective confining pressure σ'_{crit} ultimately developed by dense Ham River Sand (relative density of 0.75) tested at constant volume in a specially adapted Simple Shear Apparatus. Find the corresponding critical state shear strength τ_{crit}. Give an example of an application where these values might be relevant.

[25%]

(c) Use the definition of relative dilatancy to estimate the peak angles of friction ϕ_{max} and dilation ψ_{max} of two further identical samples, but sheared at constant vertical effective stresses of 0.1 σ'_{crit} and 0.01 σ'_{crit} respectively.

[25%]

(d) Compare linear and power-law fittings of peak strength envelopes for the Ham River Sand at a relative density of 0.75, using your results from (b) and (c). Point to some dangers in defining a "true cohesion" for dilatant soils.

[25%]

END OF PAPER

Part IIA Paper 3D1 2003 Answers

1. a) points (w, e) are (0.06, 0.472), (0.10, 0.400), (0.14, 0.420), (0.18, 0.523)
   to find saturation lines in this range, use $w = S_r\, e / G_s$ for e = 0.4 and 0.5
   optimum compaction at e = 0.39, ρ_d = 1906 kg m^{-3}
   ρ_d is preferred to e because it does not require a measurement of G_s
   field compaction is calibrated against Proctor test, e.g. by energy per unit volume
   b) optimum water content 11%
   wet of optimum water is trapped in voids and prevents compaction
   dry of optimum air is trapped, with macro-pores held open by fines in suction
   c) true that soil suction on dry increases effective stress, stiffness and strength
   not true that soil overall will swell – the fines in suction swell and soften so that macro-pores will collapse on wetting, giving overall settlement
   engineer should demand $w > 11\%$ and $e < 0.45$, say to keep $S_r > 0.75$

2. a) $E_o \approx 476$ kPa, $C_v \approx 5.7 \times 10^{-8}$ m^2 s^{-1}, $k \approx 1.2 \times 10^{-9}$ ms^{-1}
   b) $\Delta\sigma'_v \approx 35$ kPa in the field instead of 50 kPa
   correct E_o by assuming a λ-line, $E_o \approx 390$ kPa
   $k \approx 1.2 \times 10^{-9}$ ms^{-1} as before, $C_v \approx 4.8 \times 10^{-8}$ m^2 s^{-1}
   c) $\rho_{ult} \approx 0.54$ m, $\rho_{1\,year} \approx 0.46$ m taking d = 1.5 m
   45700 tonnes
   corrected $\Delta\sigma'_v \approx 40$ kPa
   field trial fill to confirm, especially rate of drainage

3. a) compression on λ-lines, on yield surfaces, involves grain crushing and rearrangement
   unload-reload on κ-lines involves grain contact elasticity, with some rearrangement
   b) for A go to 206 kPa, for B go to 500 kPa and then swell to 50 kPa
   c_u = 47 kPa, A→C δu = +95 kPa, B→C δu = -61 kPa
   c) normally consolidated soil A will settle too much if it drains, but it gets stronger
   overconsolidated soil B will soften too much if it drains, and swell slightly

4. a) grain crushing, critical friction
   b) σ'_{crit} = 3954 kPa, τ_{crit} = 2471 kPa for constant volume shearing, e.g. pile driving
   c) 40.6°, 10.8°; 49.3°, 21.6°
   d) at σ' = 395 kPa, τ_{max} = 339 kPa; at σ' = 39.5 kPa, τ_{max} = 46 kPa
   straight line will not fit critical state and implies strength at zero effective stress
   power law works perfectly for β = 0.86